Erosion Behavior of Steel Pipes Carrying of Some Iraqi Crude Oils

Dr. Ali H. Ataiwi
Engineering College, University of Kofi/ Iraq.
Email: ali.alomairy@uokufa.edu.iq,
Dr. Ayad K. Hassan
Mateterials Engineering Department ,University of Technology/Baghdad.
Ban A.F. Al-Saadi
Mateterials Engineering Department ,University of Technology/Baghdad.
Email:banabd_68@yahoo.com

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ABSTRACT

This paper deals with erosion that is defined as a process of progressive removal of material from a target surface due to repeated impacts of solid particles for the special case of two phases (liquid and solid). Experimental investigation dependence on erosion rate in different Iraqi oils obtained from Baghdad East Field (Al-Khaseb oil (Kh) and Al-Tanoma oil (T)) and from Al- Durra Refinery (Al-Stratege oil (ST)). The effect of impact angle and testing time on erosion rates has been analyzed. An erosion devise is fabricated and special fixtures have been developed to conduct erosion tests at various impact angles (30°, 45°, 60°, and 90°). Experiments have been conducted in oil in absence and presence sand of concentration (1.74 wt. %) with three particle sizes (600 µm, 850 µm and mixture of two) at the velocity of (8.4 m/s). The results indicated that the increasing of impact angle led to decreasing erosion rate.

Keywords: Erosion Rate, Impact Angle, Particle Size, Silica Sand.

سلوك التعرية لأنابيب الفولاذ الناقل لبعض أنواع النفط الخام العراقي

الخلاصة:

يتناول هذا البحث التعرية التي تعرف على انها عملية تدريجية لإزالة سطح المواد المستهدفة نتيجة الاصطدام المتكرر للحبيبات الصلبة في السائل . وقد اجريت التجارب المختبرية لقياس معدل التعرية لأنواع مختلفة من النفط العراقي مجهزة من حقل شرق بغداد (نفط الخصيب Kh) ونفط تنومة T)) ومن شركة مصافي الوسط/مصفى الدورة (نفط الاستيراتيجي (ST)) . لقد تم دراسة تأثير زمن وزاوية الاصطدام على معدل التعرية . وقد تم تصنيع وتطوير جهاز لإجراء فحص التعرية عند زوايا مختلفة (30°, 45°, 60°, and 90°). وقد اجريت هذه التجارب بغياب او وجود رمل السليكا بتركيز (1.74 wt. %) بثلاث حجوم حبيبية (600 µm و 850 µm ومزيج من كليهما) وبسرعة (8.4 m/s). وبينت النتائج بأن زيادة زاوية الصدم تقود الى نقصان معدل التعرية .

INTRODUCTION

Erosion wear is described as the progressive loss of original material from a solid surface due to mechanical interaction between the surface and a fluid which may be a multi-component fluid or impinging solid or liquid particles. It is common that the materials used in pipes, bends, tank, etc. in industries like chemical, cement, mining and mineral processing and thermal power plants encounter erosion related problems [1].

It is one of the important problems in various gas and liquid flow passages such as flow in pipes and pipe fittings (valves, bends, elbows, flow meters,... etc.), flow in pumps, turbines, compressors and many others. Erosion may cause equipment failure (vibration, leakage, excessive energy losses,... etc.) and may also lead to complete failure of machine components.

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

Accurate prediction of the rate of erosion in a specific application is one of the very complicated problems since it requires detailed investigation of the solid particle motion before and after impact. The difficulty arises mainly from the fact that most flows occurring in industrial processes are turbulent which makes the particle trajectory and impact characteristics difficult to predict taking into consideration all fluid forces acting on the particle [2].

Erosion wear plays an important role in the design of transportation system like pipe and pump. Therefore it is essential to understand the process of erosion. Erosion takes place due to cutting and deformation. Cutting wear is associated with particle velocity parallel to the wear surface whereas deformation, wear is associated with particle velocity normal to the wear surface [3].

The deformation caused by an angular particle depends on the orientation of the particle when it comes into contact with the surface and whether the particle rolls forward or backwards during contact [4].

The erosion rate (ER), is the common parameter used to measure the resistance of a material to erosion and may be expressed in terms of mass or volume of the material removed per unit mass of the erodent impacted.

$$ER = M / t \qquad ..(1)$$

Where

ER : Erosion Rate.

M : Mass of eroded materials.

t : Time [5].

Patil et al. (2011) [6] found that erosion wear is recognized as an engineering problem for equipment. They reported experimental investigations on dependence of erosion wear of aluminum in sand – water. Aluminum has been chosen for target material as representative of ductile material. The effect of various parameters such as impact angle, particle size, velocity and solid concentration on erosion wear of aluminum has been analyzed. The results show that the erosion wear of aluminum increases with increasing in impact angle attaining a maximum at (45^0) and then reduces at (90^0). The erosion wear of aluminum increases linearly with increase in particle size. Velocity has dominant effect on erosion wear. At higher velocity, the weight loss in the reduced duration was significant.

Jha et al. (2011) [7] studied effect of sand in water. Samples were mounted at various angles and rotated at different speeds. The results showed that wear rates increase with increasing impingement angle up to (90°). Contrary to the conventional understanding of maximum loss of ductile material at about (45°) impingement angle, maximum wear rate was observed in sample fixed at (90°).

AL-Marahleh et al. (2013) [8] noted that the amount of surface material eroded by solid particles in a fluid stream depends on the conditions of fluid flow and on the mechanism of material removal. This study analyzes the mechanism of material removal for ductile and brittle materials. For ductile material, it is noted that erosion produced by particles striking the surface at shallow angles (15^o, 30^o) but the maximum erosion in brittle materials at perpendicular impact at (90^o).

Islam et al. (2014) [9] studied erosion tests on (API X42) steel using aluminum oxide as erodent. Erosion tests were carried out under high mean abrasive feed rate of ($160\ g\ min^{-1}$). Particle velocities and attack angles employed were as follows: ($36\ m\ s^{-1}$), ($47\ m\ s^{-1}$), ($56\ m\ s^{-1}$) and ($81\ m\ s^{-1}$) at (30°), (45°), (60°) and (90°), respectively. Similar to erosion at low abrasive feed rate, it is found that erosion rate decreases with increasing impact angle and increases with increasing particle velocity.

The aim of work

The aim of work is study the erosion problem in steel pipes in crude oils in absence and presence sand with three particle sizes at different time and different impact angles to estimate the effect of variables on erosion rate.

Experimental Work

Low carbon pipe steel (A 106-ASTM) has been obtained from (Al-Durra Refinery / Ministry of Oil) was used in this work to study the erosion wear in crude oil. Spectrometer inspection has been performed on the selected alloy in order to give the chemical composition of the alloy. Table (1) gives the chemical composition of the alloy.

Table (1) Chemical composition of low carbon steel

Element	C	Si	Mn	Cr	Ni	Al	Fe
Wt. %	0.18	0.29	0.55	0.014	0.03	0.02	Balance

Three different crude oils are used in this work which has been obtained from (Al-Durra Refinery) and (Baghdad East Field).

Table (2) indicates the analyses of Al-Stratege (ST) from Al-Durra Refinery. This type is used as it is and also is mixed with silica sand at amount 1.74 wt. % with particle size (600 µm, 850 µm, and mixed of {600+850} µm). Tables (3), (4) indicate the analyses of Al-Tanoma oil (T) and Al-Khaseb oil (Kh) from Baghdad East Field respectively, these types are used without silica addition.

Table (2) Properties of Al-Stratege (ST) from Al-Durra Refinery

Test	Result
API GRAVITY	28.3
Density kg/m^3	0.8850
Water and Sediment % Vol.	0.1
Salt Content % wt.	0.0009
Water Content Vol. %	0.05
Asphaltenes Content % wt.	1.93
ASH Content % wt.	0.0290

Table (3) properties of Al-Tanoma oil (T) from Baghdad East Field

Test	Result
API Gravity	20.6
Density kg/m^3	0.9383
Water and Sediment % Vol.	3.8
Salt Content % wt.	3388
Water Content Vol. %	2.1
Asphaltenes Content % wt.	3.4
ASH Content % wt.	0.006

Table (4) properties of Al-Khaseb oil (Kh) from Baghdad East Field

Test	Result
API Gravity	22.4
Density kg/m^3	0.8996
Water and Sediment % Vol.	0.1
Salt Content % wt.	306

Water Content Vol. %	0.1
Asphaltenes Content % wt.	3.1
ASH Content % wt.	0.004

The sand preparation that was mixed with one type of crude oil was performed by sieving with special device. The chemical composition of the sand (Iraqi Sand) is shown in Table (5).

Table (5) Chemical composition of the silica sand

Element	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	Cl	Na_2O	K_2O
Wt. %	98.37	0.56	0.06	1.06	0.16	0.04	0.12	0.15

The HCl was used with concentration of (10%) to clean the steel specimens by dipping them for (5) min to remove oxides.

The erosion device used in this study was locally designed and manufactured in accordance with the test apparatus explained in American standard (ASTM G73).The principal scheme is shown in figure (1). A plastic (Perspex) tank is used as a chamber. The Perspex tank has a dimensions of (42) cm in length, (35) cm in height, and (24) cm in width. The different media (oil with or without sand) are delivered directly at horizontal direction of the specimen face through jet nozzle by a pump sucking the different media from plastic tank (chamber) with (1) horse power, single phase electric motor (Diesel Oil Pump). The diesel oil pump is resistant to the slurry and crude oil. The pipe joints and valves connected to the chamber with diesel oil pump are made from rubber to resist crude oil and slurry while the jet nozzle made from low carbon steel. A close flow loop for the jet impingement apparatus was designed with test specimen mounted or fixed by special tool (fixer) directly in front of the orifice of the jet nozzle, that is used in case weight loss by erosion (2-1).

The samples are cut from a pipe with length (500 mm), internal diameter (50 mm), external diameter (60 mm), and thickness (5 mm). The samples have been cut with dimensions (30*26*5) mm.

Figure (1) shows the erosion device. Figure (2) shows erosion device drown by Auto CAD and table (6) shows the contents of device.

Figure (1) Erosion device

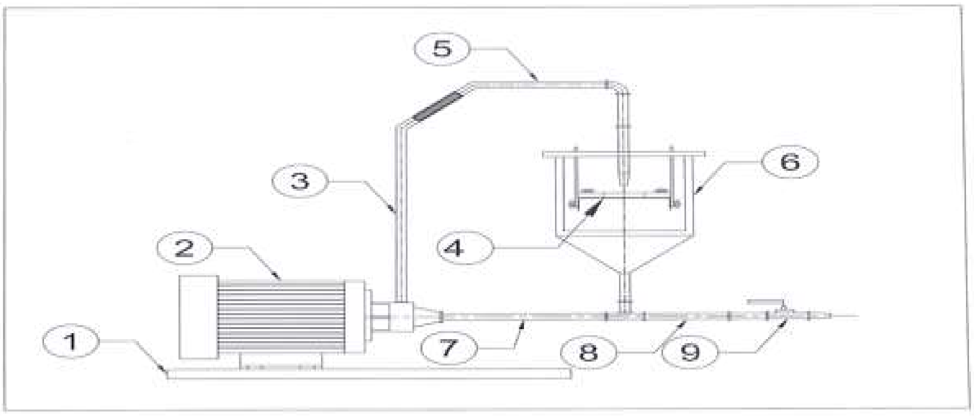


Figure (2) Erosion device AutoCAD

Table (6) Contents of erosion device

Contents	
1	Plate form
2	Oil pump
3	Rubber pipe
4	Specimen with holder
5	Rubber pipe
6	Chamber
7	Pipe (0.5) inch
8	Pipe (0.5) inch
9	Outlet

Results and Discussion
Effect of Impact Angle

One of the most important characteristics of erosion is the variation of erosion rate with impact angle. Determining the effect of the impact angle on erosion is the most sensitive way of studying the mechanism of erosion [10].

Figures (3) to (5) show the variation of erosion rates of steel specimens, for oil velocity at (8.42155 m/s) and function with impact angle, test time, and type of oil.

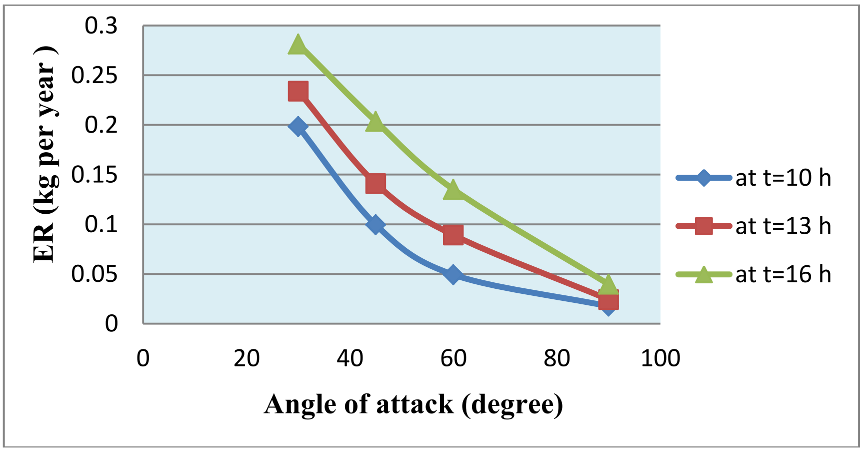


Figure (3) Effect of attack angles on erosion rate at different time in (ST) oil in absence sand

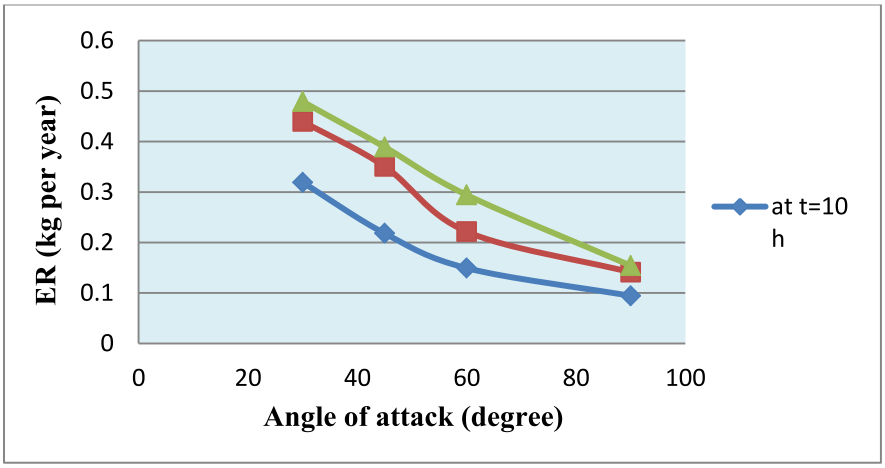


Figure (4) Effect of attack angles on erosion rate at different time in (Kh) oil in absence sand.

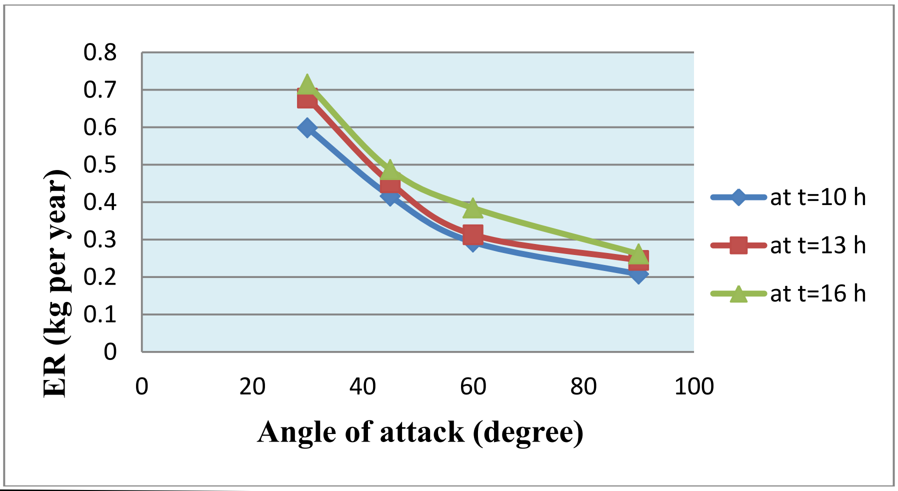


Figure (5) Effect of attack angles on erosion rate at different time in (T) oil in absence sand

Table (7) shows maximum and minimum erosion rate of steel specimens at different crude oils, times and impact angles.

Table (7) Erosion rates for steel specimens at different times and impact angles for three types of crude oil.

Oil Type	Erosion rate (kg per year) at impact angle (30^o)			Erosion rate (kg per year) at impact angle (90^o)		
T	10	13	16	10	13	16
	0.598	0.678	0.715	0.208	0.246	0.262
Kh	0.319	0.44	0.479	0.094	0.141	0.154
ST	0.198	0.234	0.281	0.018	0.024	0.04

The erosion rates of the three types of oils without addition of sand are presented in figures (6) to (8) at different impact angles and testing time.

From table (7) and figures (6) to (8), it is noticed that oil type (T) has the highest erosion rates compared with the others. This may be due mainly to the higher amount of salt and asphaltenes in (T) oil, see Tables (2), (3), and (4). The presence is much higher of salt in this oil result in corrosion rate in addition of erosion which increases the amount of removed metal from the surface.

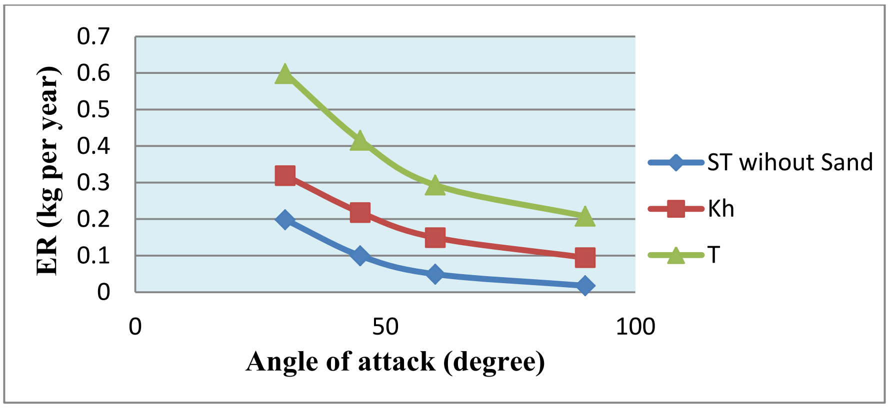


Figure (6) Effect of impact angle on Erosion rate for three types of crude oil at time (10 hours).

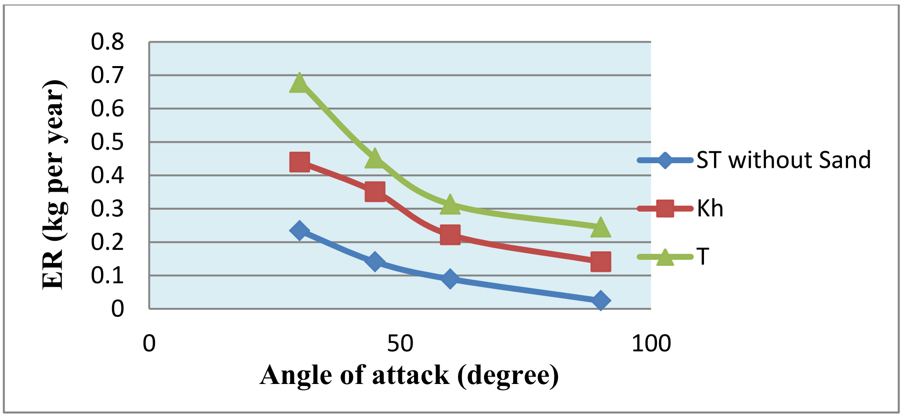


Figure (7) Effect of impact angle on Erosion rate for three types of crude oil at time (13 hours).

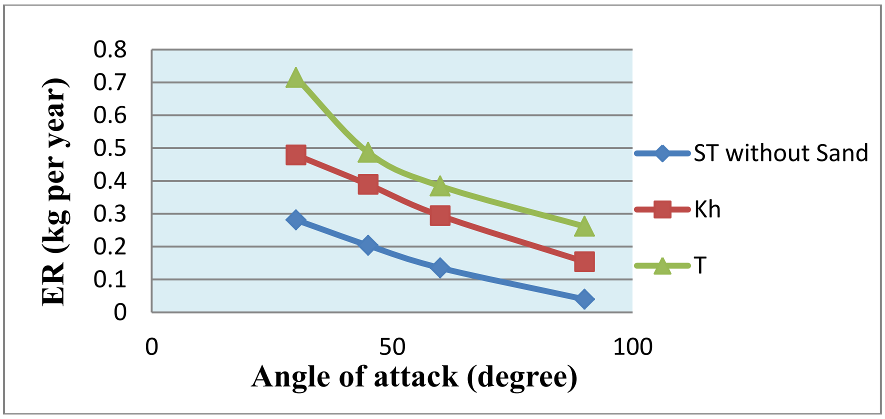


Figure (8) Effect of impact angle on Erosion rate for three types of crude oil at time (16 hours).

Figures (9) to (11) show the effect of impact angle on erosion rates in one type of oil (ST) mixed with sand of three particle size (600μm, 850μm and mixed of {600+850} μm) respectively. Among all the four impact angles, (30°) and (90°) impact angles show the maximum and minimum erosion rates respectively.

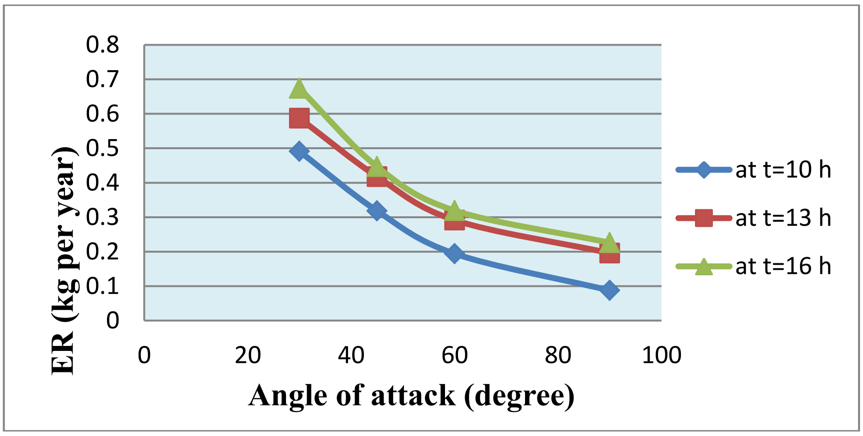


Figure (9) Effect of attack angle on erosion rate for (ST) oil in presence sand with (600) μm

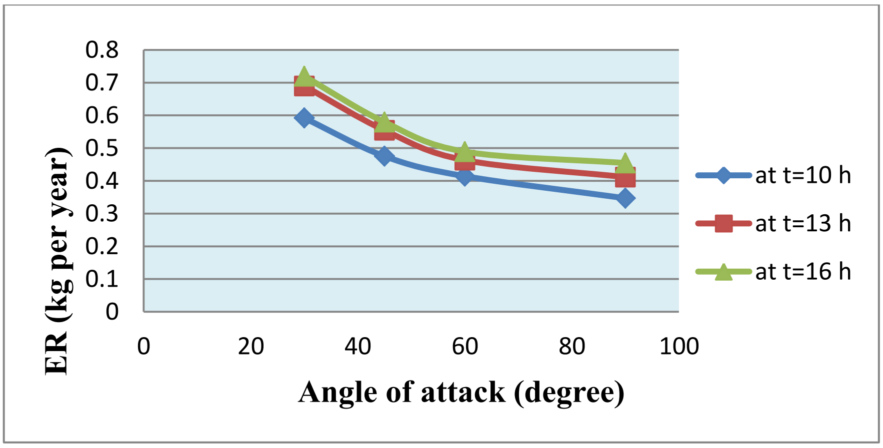


Figure (10) Effect of attack angle on erosion rate for (ST) oil in presence sand with (850) μm

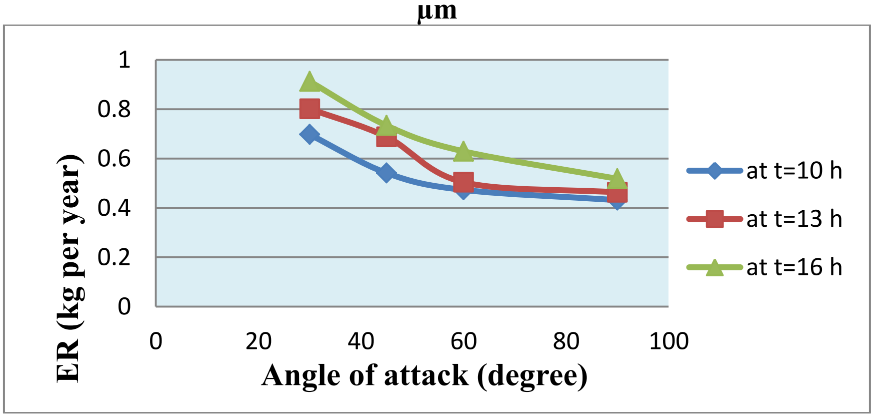


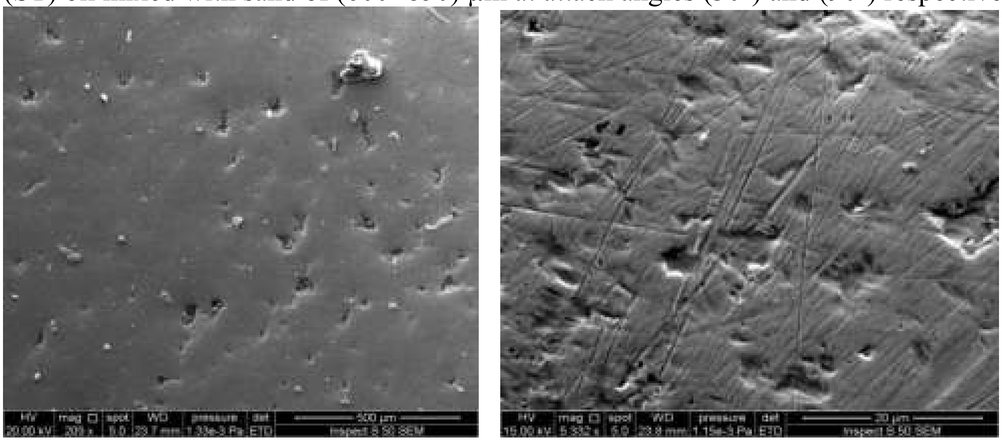
Figure (11) Effect of attack angle on erosion rate for (ST) oil in presence sand with (600+850) μm

The maximum and minimum erosion rates in steel specimens for oil type (ST) mixed with different sand grain size at (1.74%) are shown in Table (8).

Table (8) Erosion rates of steel in oil type (ST) in presence of sand at (1.74 %) and different testing times

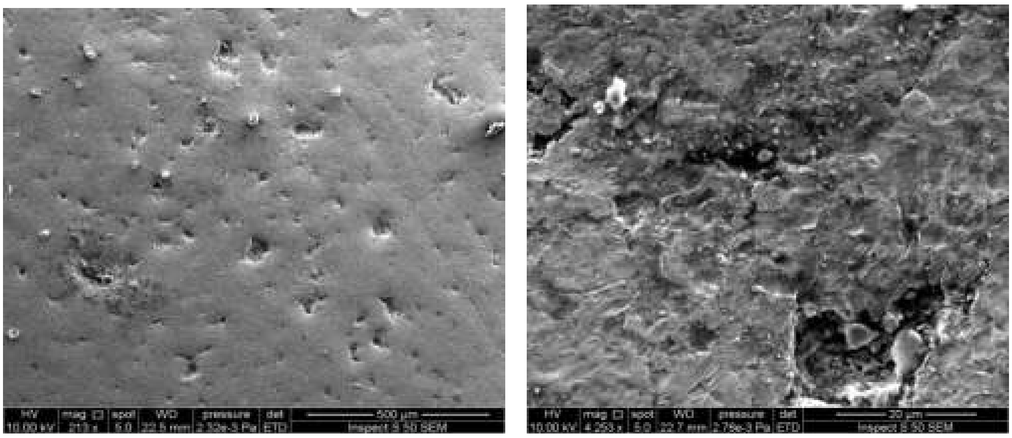
Grain size (µm)	Erosion rate (kg per year) at impact angle (30^o) for testing times (hours)			Erosion rate (kg per year) at impact angle (90^o) for testing times (hours)		
600	10	13	16	10	13	16
	0.491	0.587	0.678	0.088	0.196	0.226
850	0.592	0.69	0.720	0.347	0.411	0.454
Mixture of (600+850)	0.698	0.802	0.913	0.432	0.463	0.518

Figures (12) and (13) show the morphology of specimens (ST_{13}, ST_{16}) after erosion test by (ST) oil mixed with sand of (600+850) µm at attack angles (30^o) and (90^o) respectively.



a-(at 500 µm) b-(at 20 µm)

Figure (12) SEM specimen surface after erosion test by (ST_{13}) oil in presence sand with (600+850)µm at impact of angle (30^o) for test time (16) hours at different magnification



a-(at 500 µm) b-(at 20 µm)

Figure (13) SEM specimen surface after erosion test by (ST_{16}) oil in presence sand with (600+850)µm at impact of angle (90^o) for test time (16) hours at different magnification

It is noticed that as the grain size of sand particles is increased, the erosion rates are increased. These increments are due the increased amount of metal eroded by large particles. Furthermore, the increased erosion rates, appeared by addition of mixed size of particles

(600+850) µm, may be due to the ploughing effect done by small particles on small metal areas which are not ploughing by grand particles.

From above figures, the maximal erosion rates at low attack (impact) angles (30^o, 45^o) may be due to ploughing and cutting actions, while the erosion at high attack angles (60^o, 90^o) may be due to the deformation action.

This mechanism has been referred to as a ploughing or cutting action of the particle leading to shallow and lengthy surface indentations which are relatively smooth in nature [11, 12]. Particles travel at high velocities almost parallel to the surface and hence cutting wear is associated to the horizontal velocity component [13].

For damage at high angles of attack by demonstrating the predominance of wear by 'deformation' on ductile materials, particles penetrate deeply into the material surface which lead to material being raised along the edge of the particle leading to the formation of 'material flakes '. These flakes are removed from the surface due to subsequent particle impacts and deformation wear phenomenon [14, 15]. A major fraction of particle energy is dispensed during wear by deformation and particles almost stop at the end of the impact event and can present an obstruction to oncoming particles leading to inter particle collisions [16–19].

CONCLUSION

1. Steel pipe undergoes maximum and minimum erosion rates when the impact angles by crude oils are (30^o) and (90^o) respectively.
2. Crude oil type (T), which contains highest amount of salt and asphaltenes, showed highest erosion effect on steel pipe.
3. Oils mixed with sand of large grain size have higher erosion effect on low carbon steel.
4. Oils mixed with sand with mixed grain size have higher erosion effect than that of sand with single grain size.
5. Erosion rate of steel by oil is increased with exposure time.

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